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## Aqua/Aura Spring 2017 Inclination Adjust Maneuver Series

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## Agenda

- Recap Aqua/Aura 2017 Inclination Adjust Maneuver (IAM) Campaign
  - Maneuver Results
  - Mid-Series Planning Update
  - Aura Trending Model Update
- 2018 IAM Campaign Dates and Planning
- Aqua/Aura Latest Lifetime Mean Local Time (MLT) Term Predictions

## Aqua/Aura Spring 2017 Series Summary

- Aqua performed four inclination maneuvers between March 1<sup>st</sup> and March 29<sup>th</sup>
- Aura performed four inclination maneuvers between March 2<sup>nd</sup> and March 30<sup>th</sup>
- Aqua's third inclination maneuver was re-planned based on the results and performance differences between the first two inclination maneuvers. The fourth and final inclination maneuver was re-planned based on the results from the third inclination maneuver
- Aura's final two inclination maneuvers were likewise re-planned to maintain the phasing with Aqua requirement
- Aqua's inclination maneuvers were between 0.1% and 1.3% cold
- Aura's inclination maneuvers were between 2% and 3% cold

Note: A characteristic of Aqua and Aura inclination (INC) maneuvers includes small changes in semi-major axis (SMA) and right ascension of the ascending node (RAAN). More details on these changes in the following performance slides

## Aqua Initial Plan and Actual Performance

### Initial Plan

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
52	March 1, 2017	-86.50	550.00	1.1087	13.65	-0.00825	0.00142
53	March 8, 2017	-86.50	550.00	1.2670	11.12	-0.00817	0.00098
54	March 22, 2017	-86.50	550.00	1.3009	-105.00	-0.00840	0.00053
55	March 29, 2017	-86.50	550.00	1.2844	-99.10	-0.00810	0.00007
<b>Totals:</b>						<b>-0.03292</b>	<b>0.00300</b>

### Actual Performance

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
52	March 1, 2017	-87.30	550.00	1.2818	18.85	-0.00817	0.00119
53	March 8, 2017	-87.30	550.00	1.2758	52.30	-0.00816	0.00079
54	March 22, 2017	-90.30 <sup>†</sup>	550.00	1.3021	-23.75	-0.00829	-0.00009
55	March 29, 2017	-92.50 <sup>††</sup>	550.00	1.2875	-107.90	-0.00809	-0.00045
<b>Totals:</b>						<b>-0.03271</b>	<b>0.00144</b>
<b>Diff from Orig.</b>						<b>-0.64%</b>	

<sup>†</sup> Yaw angle adjusted due to large difference in achieved delta-Semimajor Axis (delta-SMA) between IAM 52 and 53. The IAM 54 yaw angle increased to maintain ground track error (GTE) within required bounds.

<sup>††</sup> Yaw angle increased again to achieve a more negative delta-SMA and maintain GTE within required bounds.

## Aura Initial Plan and Actual Performance

### Initial Plan

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
49	March 2, 2017	-83.80	405.00	1.3233	13.10	-0.00893	0.00174
50	March 9, 2017	-83.80	405.00	1.3271	20.10	-0.00900	0.00125
51	March 23, 2017	-83.80	405.00	1.3431	15.80	-0.00921	0.00074
52	March 30, 2017	-83.80	405.00	1.3531	-9.10	-0.00925	0.00023
					<b>Totals:</b>	<b>-0.03640</b>	<b>0.00396</b>

### Actual Performance

IAM #	Date	Commanded Yaw Angle (deg)	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
49	March 2, 2017	-83.80	395.00	1.2958	14.10	-0.00872	0.00119
50	March 9, 2017	-83.80	395.00	1.2828	8.60	-0.00875	0.00079
51	March 23, 2017	-83.80	405.00	1.3135	1.00	-0.00899	-0.00001
52	March 30, 2017	-84.50 <sup>†</sup>	410.00	1.3189	-23.50	-0.00905	-0.00045
					<b>Totals:</b>	<b>-0.03551</b>	<b>0.00143</b>
					<b>Diff from Orig.</b>	<b>-2.51%</b>	

<sup>†</sup> Yaw angle adjusted to accommodate a 4.75 sec risk mitigation maneuver (RMM) executed on 26-Mar-2017 11:10:00 UTC.

## Aura Trending Model Update

- Aura inclination maneuvers were consistently between 2% and 3% COLD
- Analysis will be performed in the upcoming months to adjust the trending model used in predicting the Aura IAM maneuver performance to reduce this error
- A similar analysis with Aqua approximately two years ago yielded improved maneuver performance

### Planned vs. Actual Delta Inclination

IAM #	Date	Planned Delta-V (m/sec)	Actual Delta-V (m/sec)	Planned Delta-Inc (deg)	Actual Delta-Inc (deg)	Difference (deg)	% Difference
49	March 2, 2017	1.3233	1.2958	-0.00893	-0.00872	0.00021	-2.44%
50	March 9, 2017	1.3271	1.2828	-0.00900	-0.00875	0.00025	-2.86%
51	March 23, 2017	1.3431	1.3135	-0.00921	-0.00899	0.00022	-2.45%
52	March 30, 2017	1.3531	1.3189	-0.00925	-0.00905	0.00020	-2.15%
					<b>Totals:</b>	<b>0.00088</b>	<b>-2.51%</b>

## Post-IAM Series Drag Make-up Maneuver Strategy

- Aqua and Aura continue to perform no-slew drag make-up (DMU) maneuvers using the mirror pole strategy
- They operate using a hybrid maneuver scheme
  - DMU maneuvers are nominally performed at alternating pole locations
  - RMM locations are dictated by conjunction timing and geometry
  - One (or more) frozen orbit maneuvers are added per year (near the end of the calendar year) to maintain frozen orbit requirements
  - DMU maneuvers performed near the start of the IAM series are planned so that they adjust the control box location in preparation for the IAMs
- With the current low-drag environment, they are using a modified targeting scheme now:
  - A four week DMU tempo is being utilized for maneuver planning
  - GTE controlled near the top of the control box
  - Allows room to execute RMMs and remain in the control box

## Post IAM Series Aqua/Aura DMUs to Date

**AQUA**

DMU #	DMU Maneuver Type	Date
117	No-Slew Mirror Pole – North	April 13, 2017
118	No-Slew Mirror Pole – South	May 10, 2017

**AURA**

DMU #	DMU Maneuver Type	Date
102	No-Slew Mirror Pole – South	May 3, 2017



## Aqua Spring 2018 IAM Campaign Planning

- The Aqua Spring 2018 IAM plan consists of five inclination maneuvers
- Proposed plan has four maneuvers occurring before the ideal burn date and one after
  - March 7, 2018 (IAM #56)
  - March 14, 2018 (IAM #57)
  - March 21, 2018 (IAM #58)
  - March 28, 2018 (IAM #59)
  - April 4, 2018 (IAM #60)
- Aqua's predicted ideal burn date occurs around March 31, 2018

**Note:** Performing maneuvers off of the ideal date slightly decreases burn efficiency

## Aura Spring 2018 IAM Campaign Planning

- The Aura Spring 2018 IAM plan consists of five inclination maneuvers
- Proposed plan has three maneuvers occurring before the ideal burn date and two after
  - March 8, 2018 (IAM #53)
  - March 15, 2018 (IAM #54)
  - March 22, 2018 (IAM #55)
  - March 29, 2018 (IAM #56)
  - April 5, 2018 (IAM #57)
- Aura's predicted ideal burn date occurs around March 27, 2018

**Note:** Performing maneuvers off of the ideal date slightly decreases burn efficiency

## Proposed Aqua/Aura 2018 Maneuver Schedule

**Aqua/Aura 2018 Inclination Maneuver Series Schedule**

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
				March 1	2	3
4	5	6	7 Aqua IAM#56	8 Aura IAM#53	9	10
11	12	13	14 Aqua IAM#57	15 Aura IAM#54	16	17
18	19	20 Equinox	21 Aqua IAM#58	22 Aura IAM#55	23	24
25	26	27 Aura Ideal Date	28 Aqua IAM#59	29 Aura IAM#56	30	31 Aqua Ideal Date
April 1 Easter Sunday	2	3	4 Aqua IAM#60	5 Aura IAM#57	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21*

\*Japan Golden Week starts April 29

## 2018 Predicted Maneuver Performance

AQUA

IAM #	Date	Commanded Yaw Angle (deg)*	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
56	March 7, 2018	-87.20	550.00	1.27596	0.16	-0.00823	0.00103
57	March 14, 2018	-87.20	550.00	1.27043	3.85	-0.00823	0.00058
58	March 21, 2018	-87.20	550.00	1.26496	7.51	-0.00820	0.00014
59	March 28, 2018	-87.20	550.00	1.25954	11.14	-0.00815	-0.00029
60	April 4, 2018	-87.20	550.00	1.25417	14.75	-0.00808	-0.00072
		* Preliminary angles			<b>Total Delta-Inc (deg)</b>	<b>-0.04089</b>	<b>0.00074</b>

AURA

IAM #	Date	Commanded Yaw Angle (deg)*	Burn Duration (sec)	Delta-V (m/sec)	Delta-SMA (m)	Delta-Inc (deg)	Delta-RAAN (deg)
53	March 8, 2018	-84.20	385.50	1.14309	6.11	-0.00861	0.00134
54	March 15, 2018	-84.70	385.00	1.13775	-7.98	-0.00861	0.00088
55	March 22, 2018	-84.70	385.50	1.13484	-8.13	-0.00863	0.00039
56	March 29, 2018	-84.70	385.50	1.13072	-8.18	-0.00861	-0.00008
57	April 5, 2018	-84.70	385.50	1.12756	-8.03	-0.00857	-0.00053
		* Preliminary angles			<b>Total Delta-Inc (deg)</b>	<b>-0.04303</b>	<b>0.00199</b>

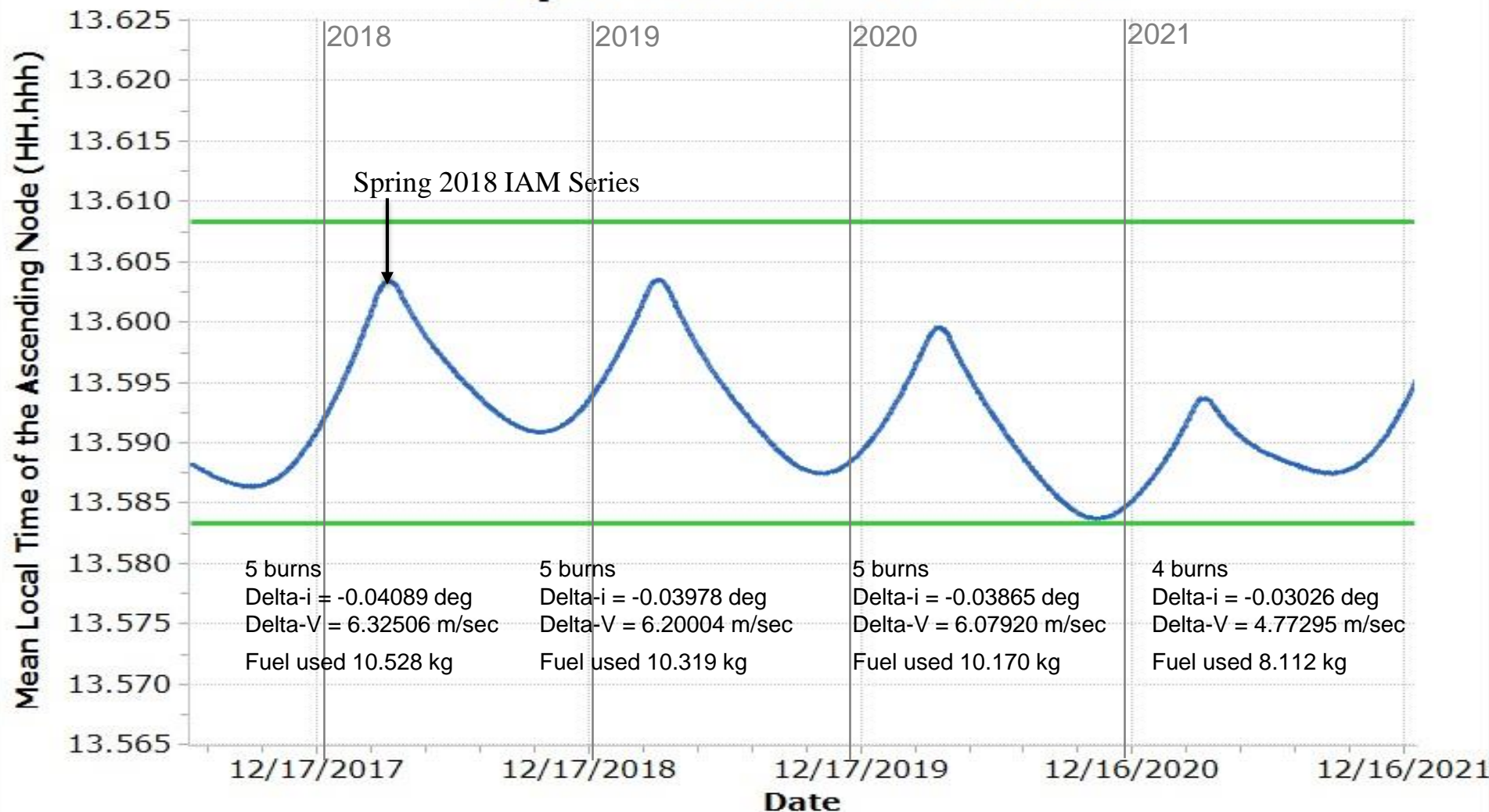
## Aqua Predicted Pre- and Post-2018 IAM MLT

### Aqua Mean Local Time



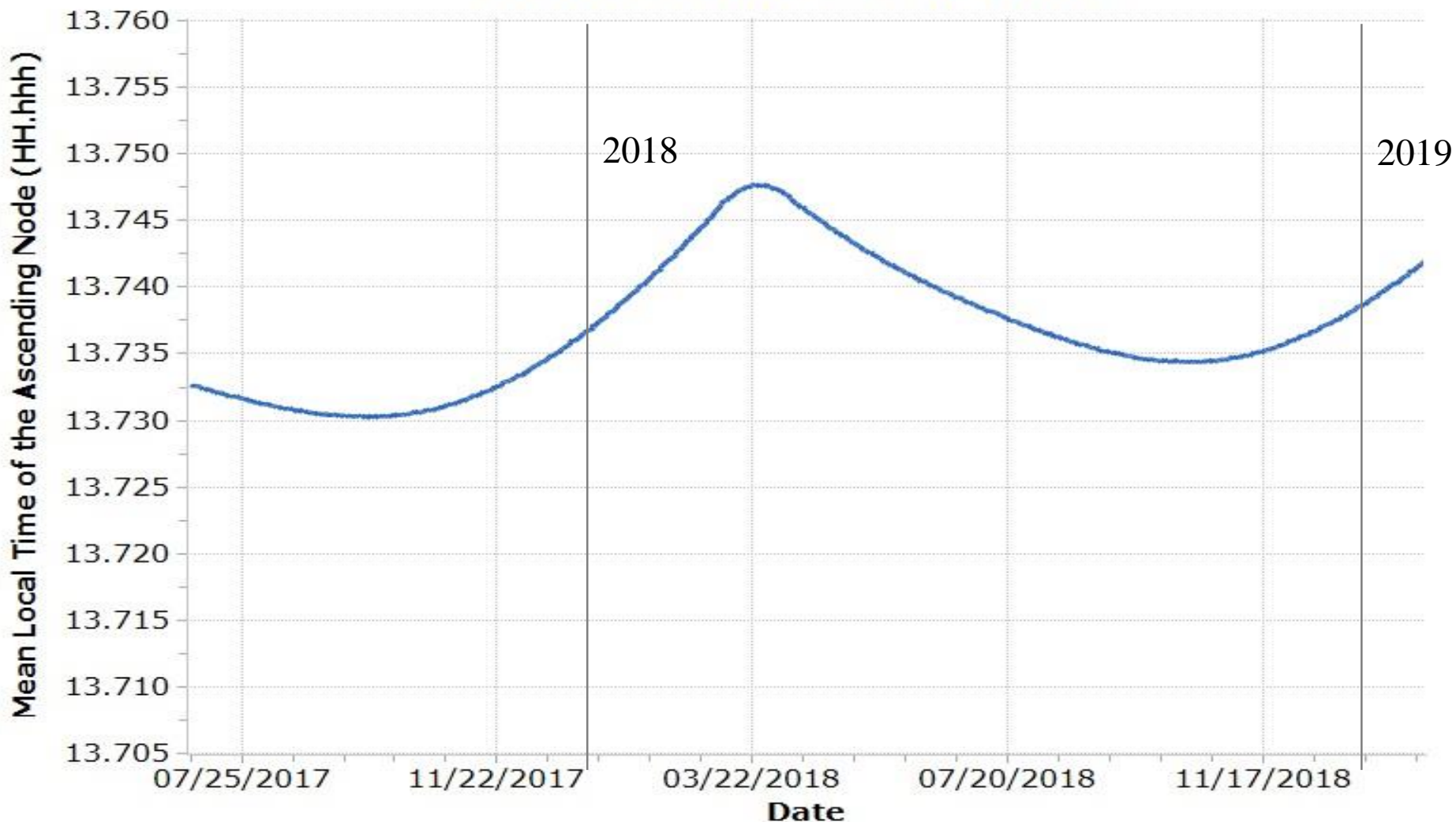
## Aqua Lifetime MLT Based on Planned IAM Strategy

### Aqua Mean Local Time



**Aura Predicted Pre- and Post-2018 IAM MLT**

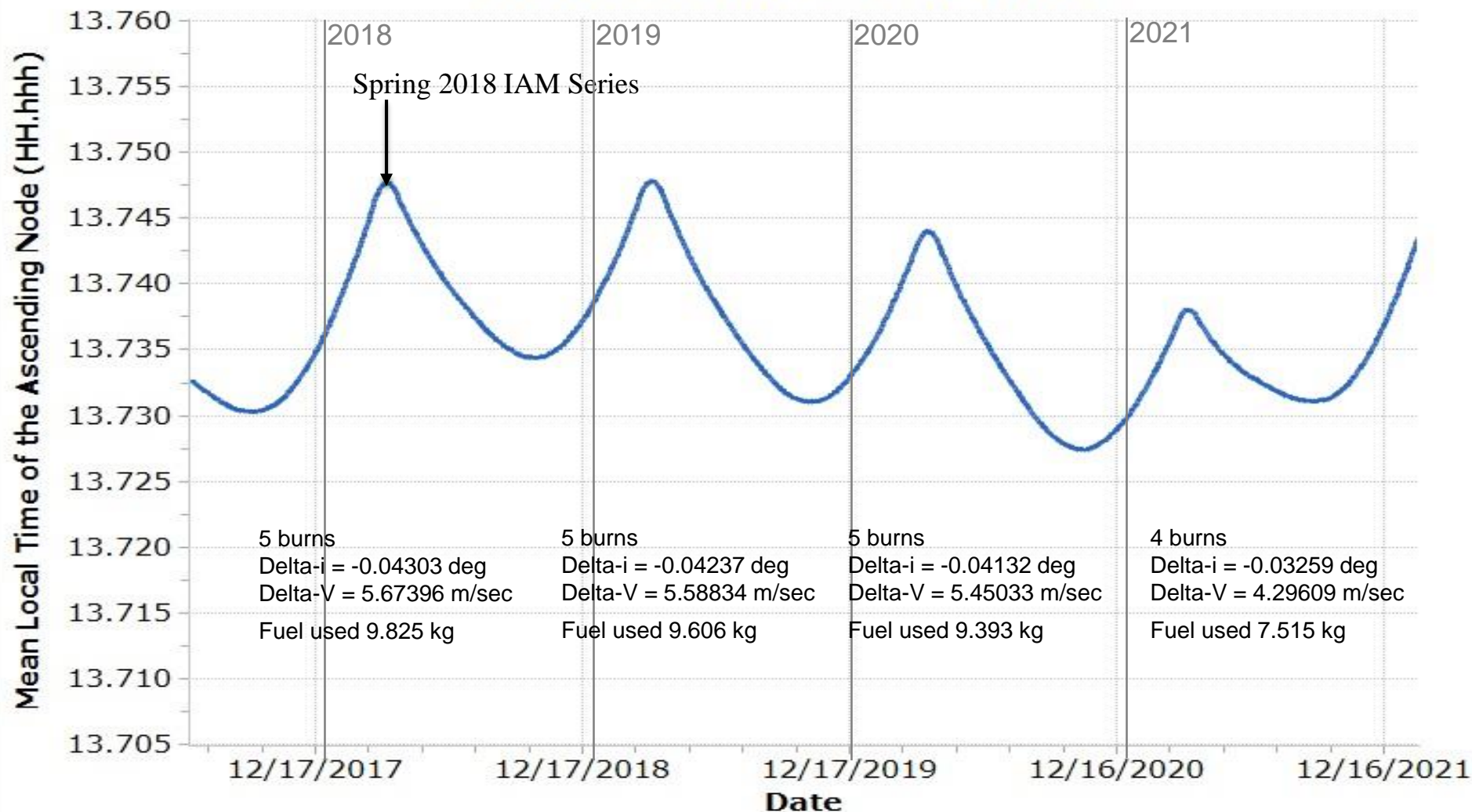
**Aura Mean Local Time**





## Aura Lifetime MLT Based on Planned IAM Strategy

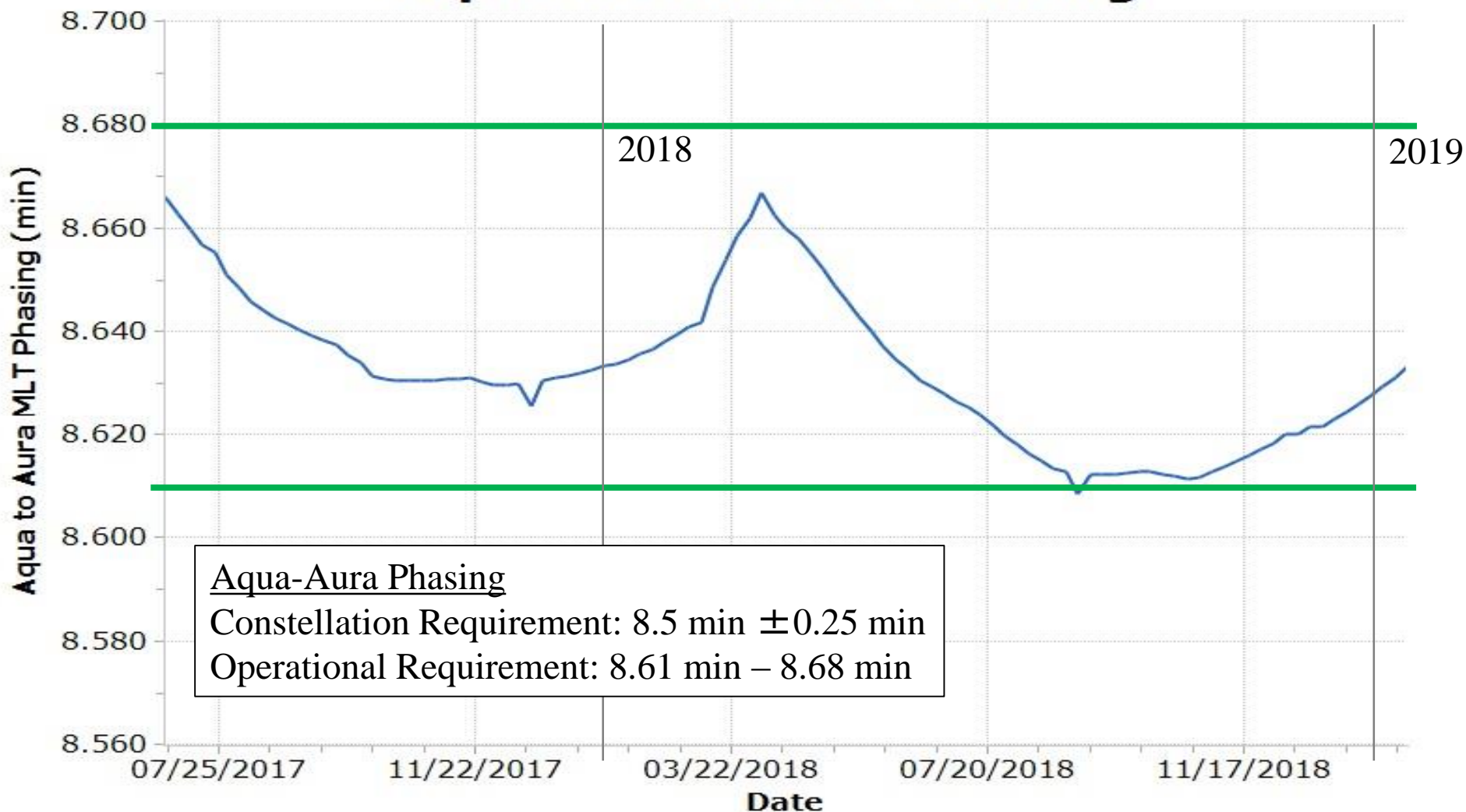
### Aura Mean Local Time





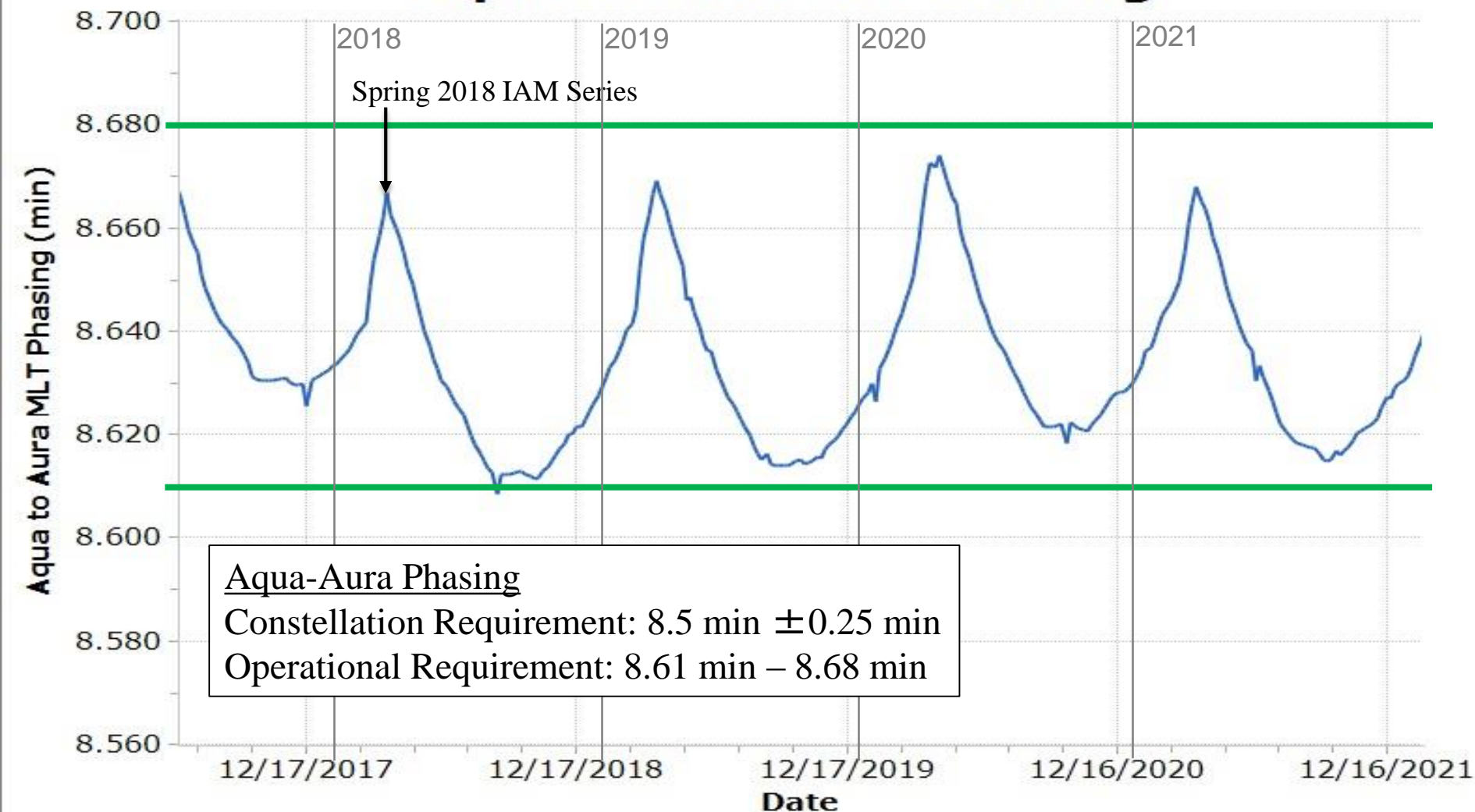
## Aqua-Aura Lifetime MLT Phasing Based on Planned IAM Strategy

### Aqua to Aura MLT Phasing



## Aqua-Aura Lifetime MLT Phasing Based on Planned IAM Strategy

### Aqua to Aura MLT Phasing



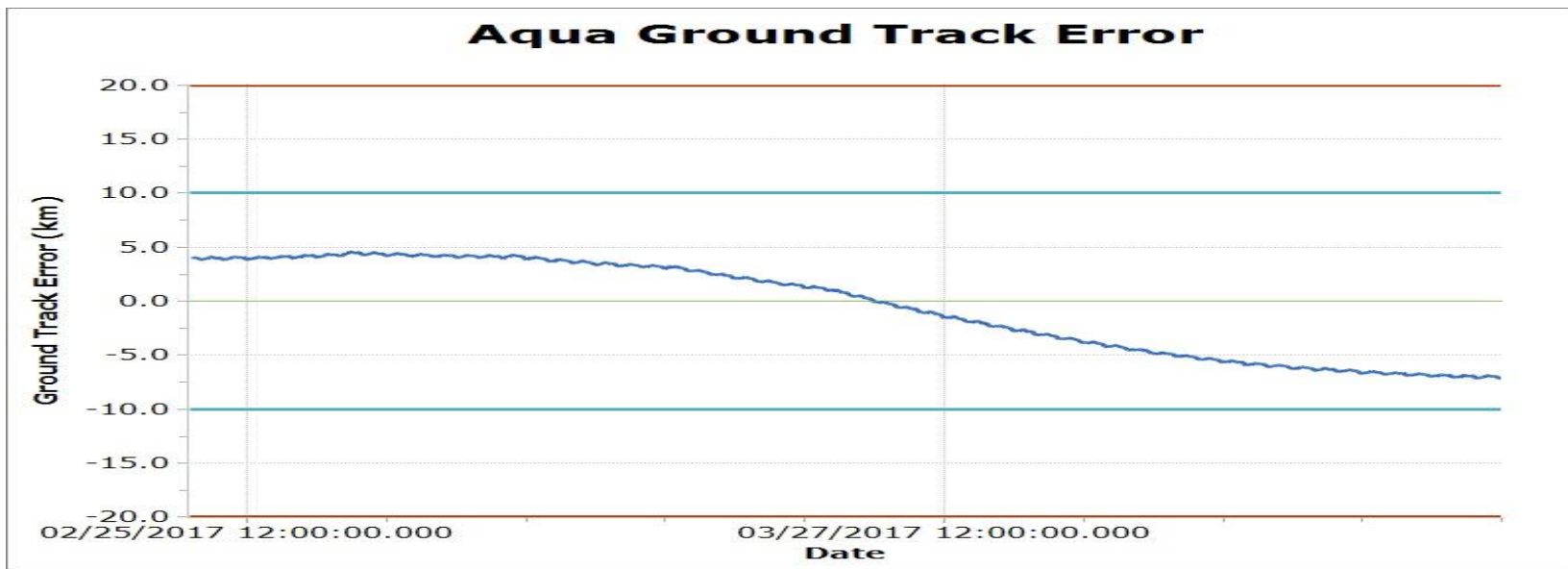
## Aqua/Aura Spring 2017 Series Summary

- Aqua performed four inclination maneuvers between March 1<sup>st</sup> and March 29<sup>th</sup>
- Aura performed four inclination maneuvers between March 2<sup>nd</sup> and March 30<sup>th</sup>
- Aqua's second inclination maneuver performed differently from the first, even though both were planned with the same yaw angle
- Aqua's third inclination maneuver was re-planned based on the results and performance differences between the first two inclination maneuvers. The fourth and final inclination maneuver was re-planned based on the results from the third inclination maneuver
- Aura's final two inclination maneuvers were likewise re-planned to maintain the phasing with Aqua requirement
- Aqua's inclination maneuvers were between 0.1% and 1.3% cold
- Aura's inclination maneuvers were between 2% and 3% cold
  - Analysis being performed to update the Aura trending model and reduce these errors for the next IAM series

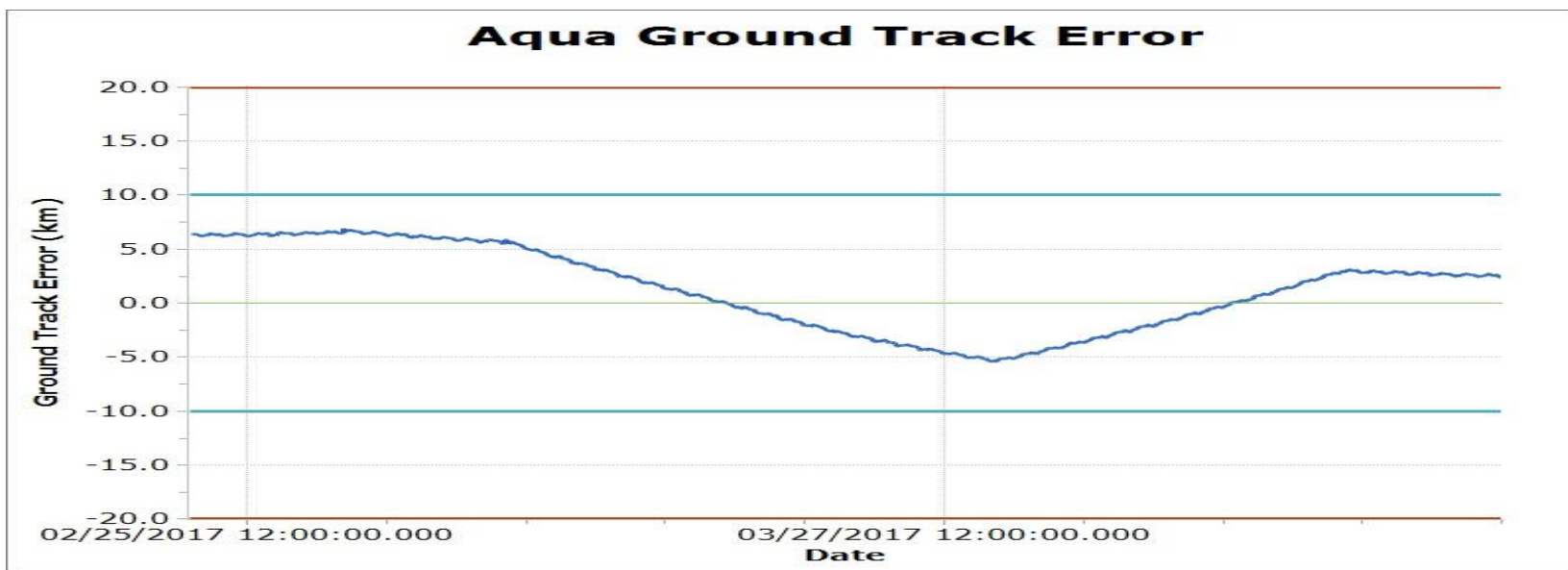
# BACKUP SLIDES

# Aqua Predicted vs. Definitive GTE Over The IAM Series

Predicted

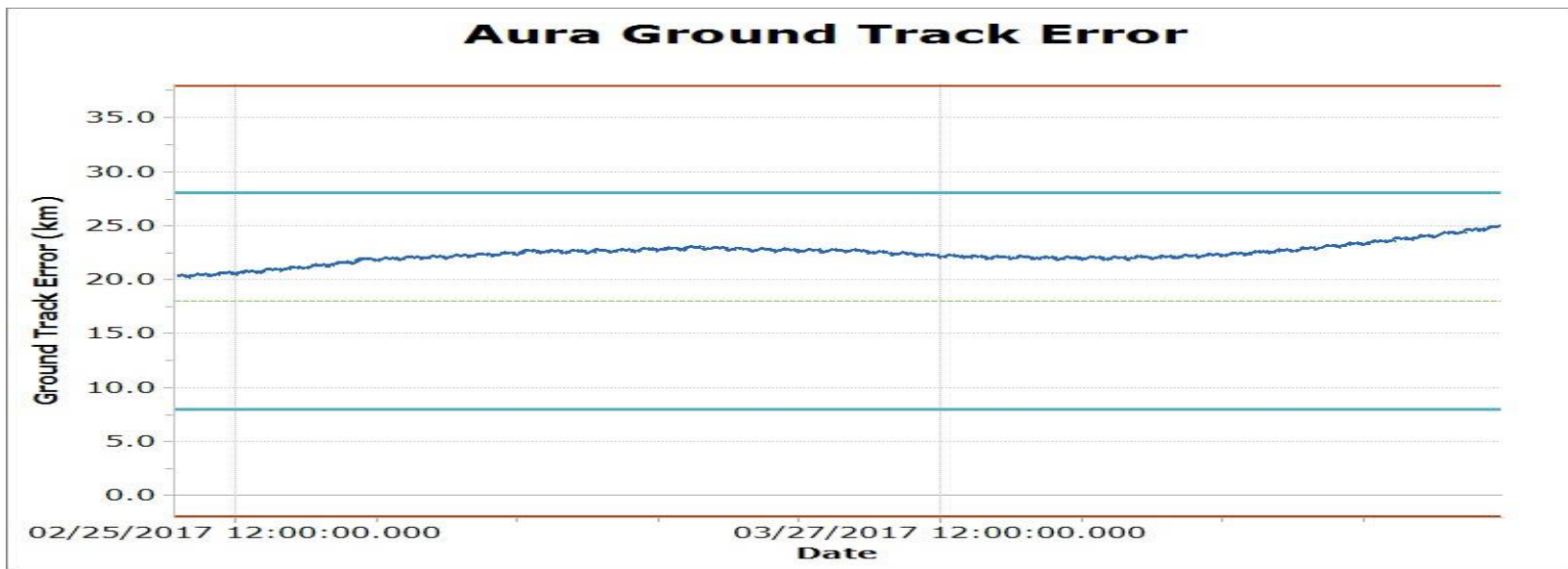


Definitive

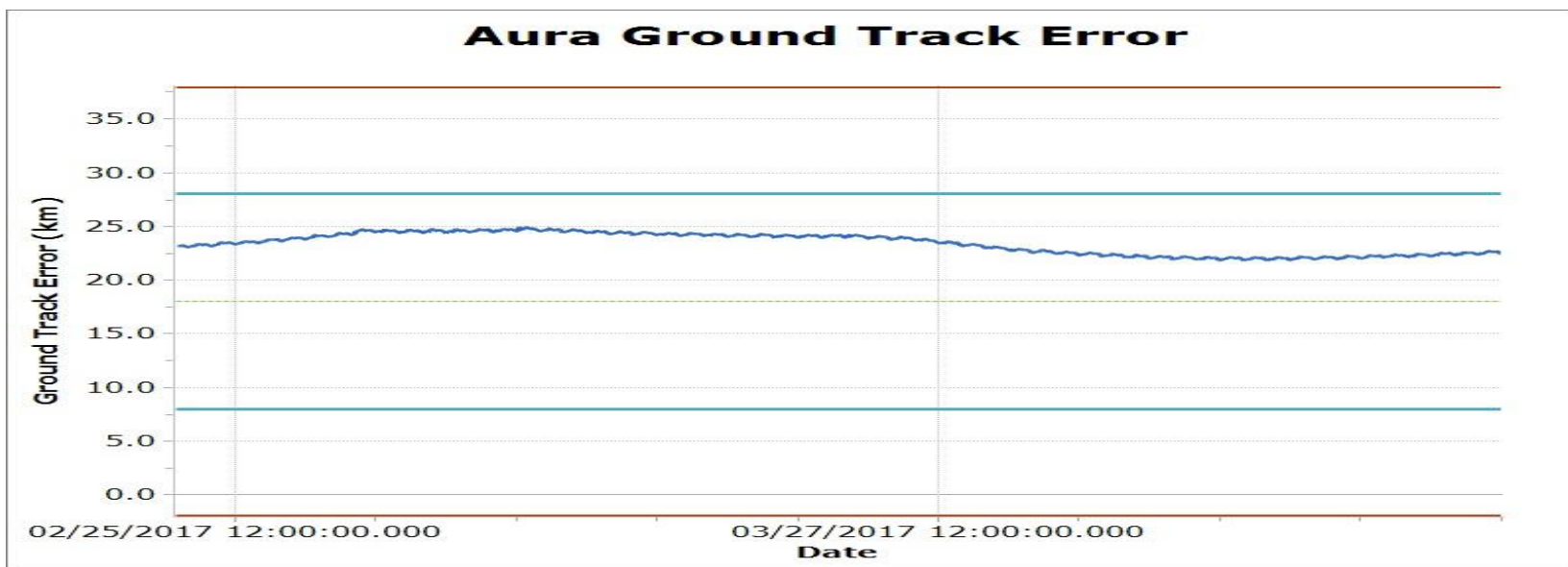


## Aura Predicted vs. Definitive GTE Over The IAM Series

Predicted



Definitive



## **Aqua/Aura Mid-Series Planning Update**

- **Aqua's achieved delta-SMA was much larger for IAM 53 vs. 52, even though both maneuvers were planned with similar inputs**
- **IAM 53 was planned using IAM 52's post-maneuver results since the maneuvers had the same yaw angle and were executed near the same orbit location.**
  - IAM 52 was planned using IAM 50's post-maneuver results due to IAM 50 having the closest yaw angle
- **IAM 53's performance was very different from IAM 52. The differences were attributed to the gyro-rate square wave significantly increasing the slew out and slew back thrust scale factors**
  - While SMA difference was larger than expected, it was still in family with previous maneuvers



## Aqua/Aura Mid-Series Planning Update

- **IAM 54 and 55 yaw angles were updated due to IAM 53's performance and the large positive SMA effect on Aqua's ground track error**
  - Predicted IAM 54 and 55 using nominal large angle process
    - Used post-maneuver results from the most similar large angle IAM
  - Updated to larger yaw angle to generate negative SMA to correct ground track error induced by IAM 52 and 53
    - Set IAM 54 to -88.3 predicted (-90 commanded)
    - Used IAM 51's post-maneuver results to predict IAM 54 since IAM 51's yaw angle (-89.5 commanded) is the closest to IAM 54
  - Created backup plan to update IAM 55's angle based on IAM 54's performance
    - Predicted nominal yaw of -85.3 but could have been more negative if necessary
- **As a contingency analysis, analyzed ground track impact of IAM 54's performance being similar to IAM 53**
  - Could have used larger yaw angles to protect against adding positive SMA
  - Could have updated IAM 55 to use a larger yaw angle based on performance



## Aqua/Aura Mid-Series Planning Update

- Below are the planning and post-maneuver values for IAM 52 and 53. Planned values are in darker blue, post-maneuver values are in lighter blue
  - Note that IAM 52's performance was cold in IAM due to a lower INC thrust scale factor (TSF). The angle off-set was greater than expected which, along with all TSF's being lower, caused the delta-SMA to be higher than expected
  - IAM 53's performance was hot in delta-SMA mainly due to significantly higher slew-out and slew-back TSFs

IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
52	13:43:54	-85.5	0.964	0.956	0.964	-0.008250	13.65
			0.937	0.965	0.937	-0.008168	18.85
53	13:50:57	-85.5	0.937	0.965	0.937	-0.008167	11.12
			0.986	0.960	0.986	-0.008157	52.30

## Aqua/Aura Mid-Series Planning Update

- Below are the planning and post-maneuver values for IAM 54. Planned values are in darker blue, post-maneuver values are in lighter blue
  - IAM 54 was planned using the performance results from IAM 53
  - IAM 54's yaw angle increased to achieve a negative delta-SMA
  - The negative delta-SMA needed to maintain GTE requirements
  - Note that IAM 54's performance was cold in IAM due to a lower INC TSF. All TSF's being lower caused the delta-SMA to be higher than expected

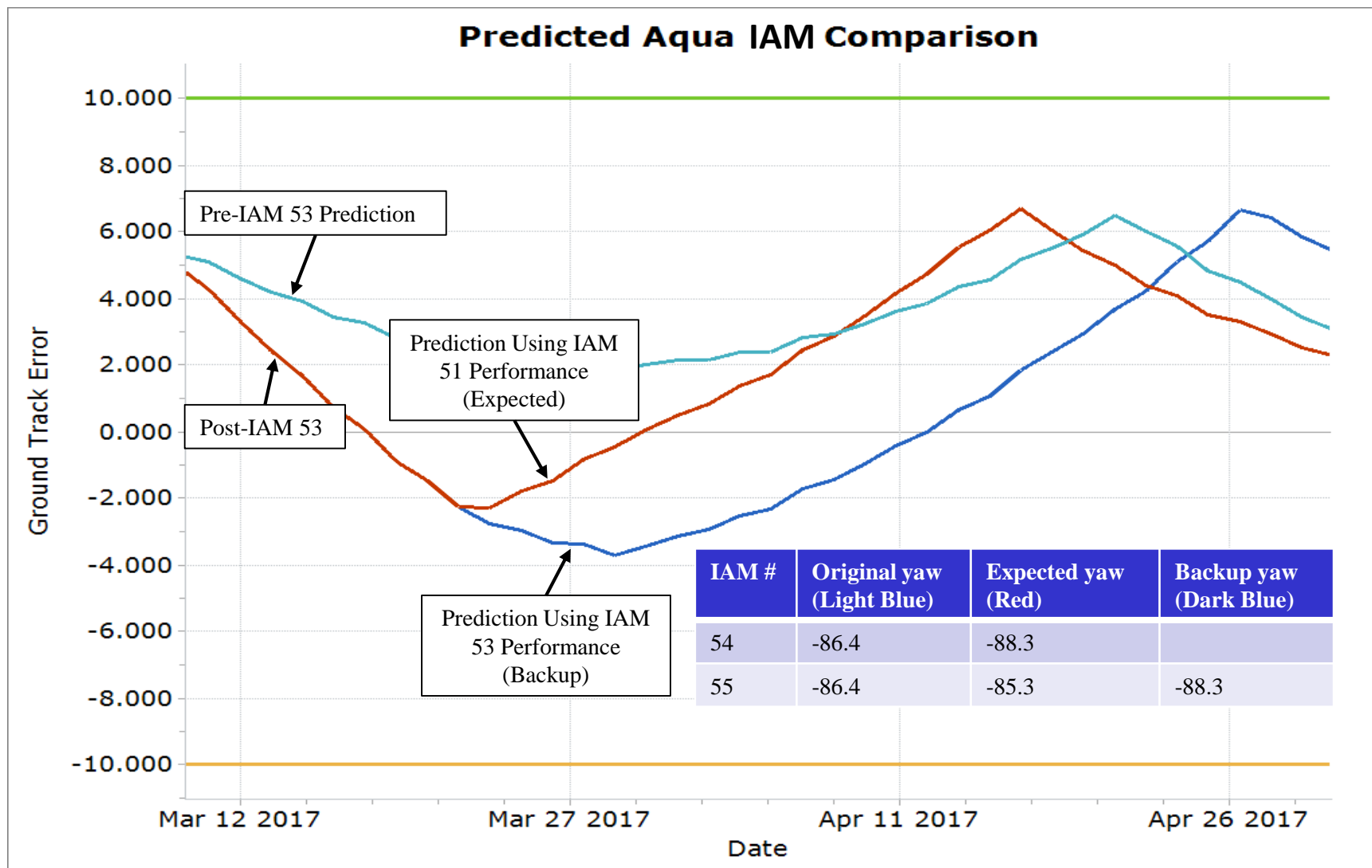
IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
54	15:44:11	-88.3	0.986	0.960	0.986	-0.008400	-105.00
			0.936	0.947	0.936	-0.008293	-23.75

## Aqua/Aura Mid-Series Planning Update

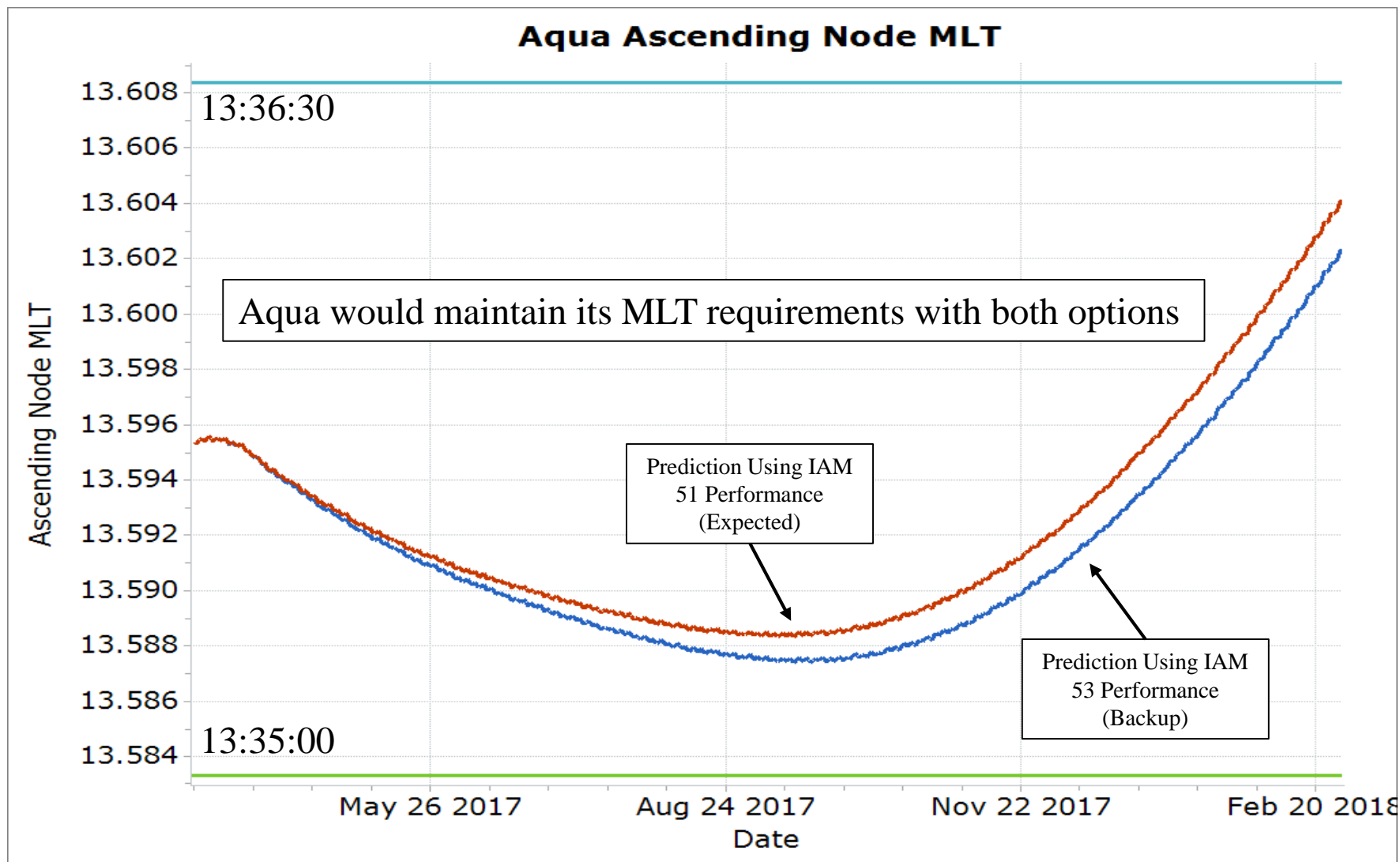
- Below are the planning and post-maneuver values for IAM 55. Planned values are in darker blue, post-maneuver values are in lighter blue
  - IAM 55 was planned using the performance results from IAM 54
  - IAM 55's yaw angle increased even more to achieve a larger negative delta-SMA
  - The negative delta-SMA needed to maintain GTE requirements

IAM #	Burn Time	Yaw	Slew Out TSF	INC TSF	Slew Back TSF	Delta-I (deg)	Delta-SMA (m)
55	15:51:17	-90.0	0.936	0.947	0.936	-0.008101	-99.10
			0.942	0.945	0.942	-0.008090	-107.90

## Aqua/Aura Mid-Series Planning Update



## Aqua/Aura Mid-Series Planning Update

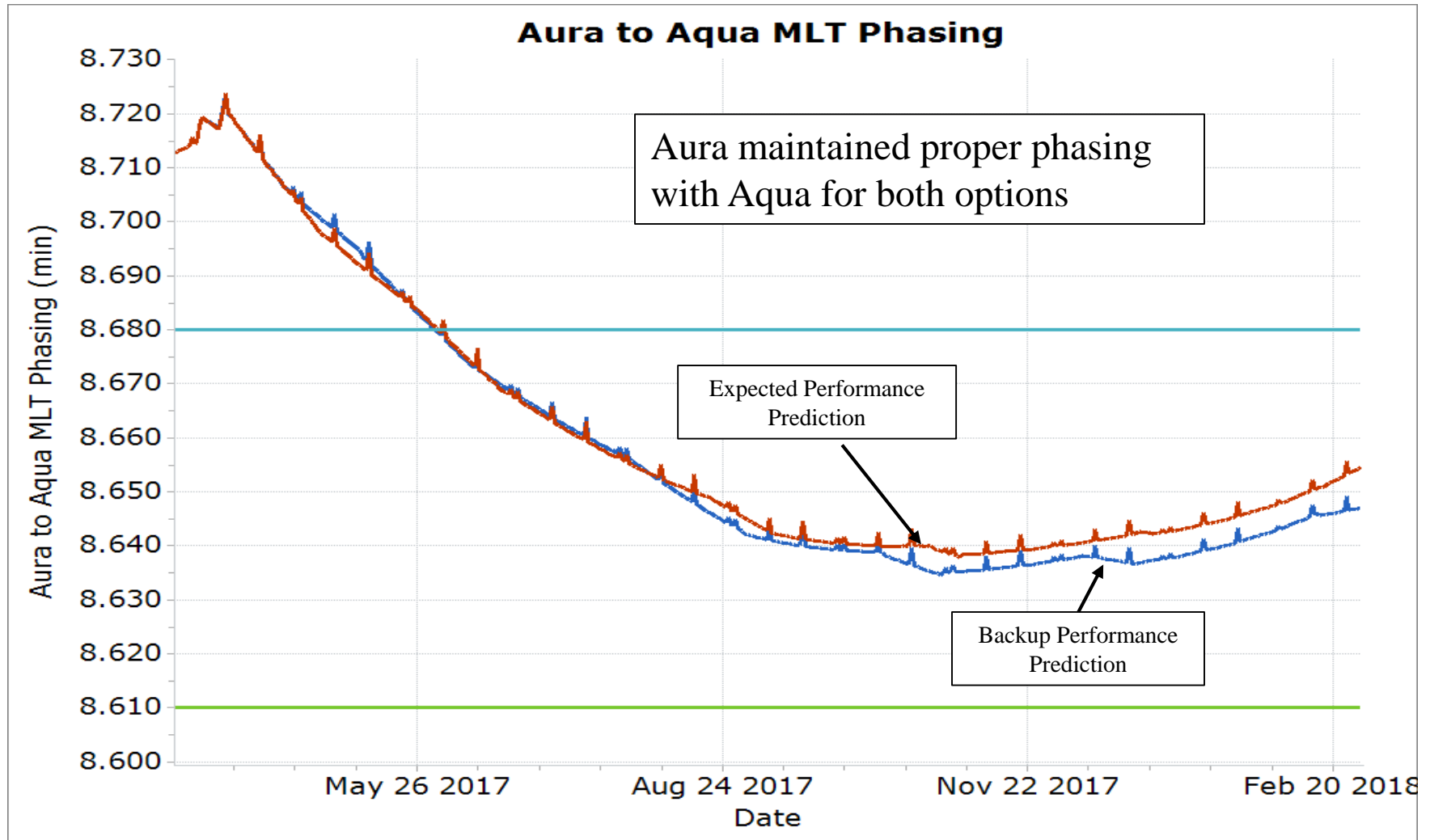


## Aqua/Aura Mid-Series Planning Update

- **Due to Aqua's performance, it was necessary to update Aura's maneuvers to maintain the MLT phasing requirement**
- **Aura's burn durations were updated and the yaw angle for IAM 52 was updated**
  - Aura's IAM 51 burn duration updated due to Aqua's IAM 53 performance
  - Aura's IAM 52 burn duration updated due to Aqua's IAM 54 performance
  - Aura's IAM 52 yaw angle updated due to Aura RMM between IAM 51 and 52

IAM #	Original Plan		Replan	
	Duration (sec)	Yaw Angle (deg)	Duration (sec)	Yaw Angle (deg)
49	395	-83.80	395	-83.80
50	395	-83.80	395	-83.80
51	395	-83.80	405	-83.80
52	395	-83.80	410	-84.50

## Aqua/Aura Mid-Series Planning Update



## Aqua/Aura Mid-Series Planning Update

